Being a scientist: the role of practical research projects in school science

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Introduction and context

This chapter explores the role practical research projects can play in engaging high school students' interest in science and improving academic performance. A number of countries offer students opportunities to engage in such projects, and this is very often this is linked to a belief that studying science in the context of real-life questions and problems is motivating for students, will improve their academic performance, and increase the chances of students wanting to continue their study of science subjects.

The research described in this chapter was undertaken in England, where considerable changes were made in 2015 to the way in which practical work is assessed in high school science courses. One outcome of the changes at the upper high school level was that practical research projects were no longer a feature of the core science curriculum. This situation gave rise to some concern and, as a result, the research reported here was commissioned[1] to explore systematically the nature of practical research projects and the claims made for their perceived benefits.

The work reported here had three principal strands. The first was a series of interviews with people in a number of countries interested and/or involved in practical research projects. The second was synthesis of research on the impact of practical research projects on students' attainment and views of science. The third was interviews with teachers and students who were involved with practical research projects.

What are practical research projects?

Practical work undertaken by students in school science lessons can take many forms. At one end of the spectrum is the 'recipe', where students follow a prescribed set of actions. At the other is the practical research project, which take the form of extended, open-ended investigations where students have a degree of control over the focus of the practical work and the way in which the work is undertaken. The investigations normally focus on a particular real-life context and, in Chemistry, such projects might take the form of comparing different forms of suncreams, exploring the function of food additives, or investigating the properties of specialist fabrics.

For the purposes of the research reported in this chapter, practical research projects are taken to be student-led, extended open-ended investigations involving practical work as defined by Millar (2004), i.e. work that encompasses activities involving students in observing or manipulating the objects and materials they are studying.

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Some examples of opportunities for students to undertake practical research projects

Box 1 shows four examples from different countries offering opportunities for students to undertake practical research projects are described briefly below to give a feel for provision. In two of the countries, Israel and The Netherlands, the practical research projects are a part of the formal school curriculum. In the other two countries, Australia and the UK, the projects are options activities to enrich the formal curriculum.

Box 1: Examples of opportunities for students to undertake practical research projects

Israel

Israel's interest in practical research projects arises from work in a number of areas. These include exploring the impact of problem-based learning and the development of a model for implementing inquiry teaching which has been implemented in Israel's high school biology teaching since 2000. The programme has been developed collaboratively by teachers, science education professionals and ministry of education staff over a period of several years.

One example of practical project work in Israel may be found in the *BioInquiry* biology curriculum (formerly the *Biomind* curriculum). This is compulsory for all high school students specialising in biology in their final two years (ages 16-18). The overall aim of the programme is that students engage in autonomous research, supported by their teachers. This involves students designing their inquiry, undertaking laboratory work, study excursions to learn practical skills such as making observations and taking measurements in the field, and writing a scientific report.

The Netherlands

The Netherlands has an education system where there is considerable choice, with clear vocational and academic routes. Of the four available routes, three (the VMBO, HAVO and VWO) require students to carry out a 'Profielwerkstuk'; a practical research project performed independently or in small groups. The Profielwerkstuk has two aims: to deepen theoretical knowledge about a topic of the student's choice, and to learn research skills such as formulating research questions, devising a method, collecting and analysing data. The topics must be related to one of the following four subject clusters: Nature and Technology, Nature and Health, Economy and Society, Culture and Society. Each student works on their Profielwerkstuk for 80 hours and, as well as producing a formal report, also present their work at school for other students or parents. Over half of the pre-university students choose to situate their research in the Nature cluster, resulting in almost 20,000 science-related investigations each year. Many of these investigations are carried out at school, though some take place at universities.

Additionally, each year, the Dutch Royal Society organizes a competition to select the best twelve Nature and Technology projects, and similar competitions are also organized by universities. Schools often use the Profielwerkstuk as the end of a research learning progression line at secondary school, to help prepare students for higher education.

Australia

Australia is currently promoting open investigative work through one of the three main strands in its curriculum, 'Science Inquiry Skills'. This requires students to identify and pose

questions, plan and conduct investigations, to analyse and interpret evidence and to communicate their findings.
Schools in Australia can participate in the BHP Billiton Science Awards, a competition, funded by BHP Billiton and administered by the Commonwealth Scientific and industrial Research Organisation (CSIRO). One of the aims of the BHP Billiton Award scheme is to encourage students to continue their study of science. The scheme has been running since 1983 and is open to primary and secondary students to work on a project in one of four categories (biology and microbiology; chemistry and biochemistry; physics, engineering and technology; and environmental and earth science) either as individuals or in groups of up to three students. The awards take the form of cash prizes.
The UK
Schools in the UK can participate in several optional schemes, one of which are the CREST (CReativity in Engineering, Science and Technology) awards. The aim of the awards is to develop practical and problem-solving skills through engagement with a project. The awards are available to students aged 11-19, with different levels of award (bronze, silver and gold) available for particular age groups. The gold awards are aimed at upper high school students (ages 16-19) and involve the undertaking of an in-depth project associated with approximately 70 hours of study. A gold level project has to be self-directed and contribute something unique to the scientific or technological community. Normally, students work in collaborative teams on projects, and they are encouraged to seek support from a mentor who works in a STEM (Science, Technology, Engineering, Mathematics) field related to their project. Assessment is via an externally-assessed report.

Why are practical research projects seen as important?

Perspectives from the research literature

There appear to be two main reasons in the research literature for promoting the use of practical research projects in school science. Firstly, the notion of 'the student as scientist' is attractive as it permits students to find things out for themselves by pursuing an idea about which they are curious. Linked to this, practical research projects are seen as a means of providing students with a realistic taste of scientific research that might motivate them to undertake further study of science. Secondly, a number of broader, international initiatives and approaches of the last twenty years or so have promoted the use of activities that have many of the characteristics associated with practical research projects. Such approaches include 'inquiry-based science', 'problem-based learning' in science and 'authentic science'. Each of these is now considered briefly.

Inquiry-based learning in science

Inquiry-based learning is a term widely used in the context of science teaching. Minner, Levy and Century (2009) undertook a research synthesis of inquiry-based learning in science which established that one of the ways in which the term inquiry-based learning is used is to describe opportunities provided for students to undertake practical projects researching a science problem in the context of the real world. Drawing on the work of the National Research Council in the USA, Minner *et al.* (2009) cite six core components of inquiry-based learning for learners: (1) they are engaged by scientifically-oriented questions; (2) they give priority to evidence, which allows them to develop and evaluate explanations that address scientifically-oriented questions; (3) they formulate explanations from evidence to address scientifically-oriented questions; (4) they evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; (5) they communicate and justify their proposed explanations; (6) they design and conduct investigations.

Problem-based learning

A problem-based learning (PBL) approach involves students learning through seeking to investigate, explain and resolve meaningful problems. PBL has its origins in a drive to make teaching in medical schools more meaningful but has now been used in a variety of subjects, including science. Students work collaboratively in small groups to try and resolve a problem, and the teacher acts as a facilitator to support and guide student learning (see, for example, Hmelo-Silver, 2004; Krajcik and Blumenfeld, 2006).

Authentic learning

Authentic learning is a term applied to learning that enables students to engage with real-world , contextualised problems. Roth (1995) argued that for school science activities to be authentic, students need to experience scientific inquiry that has features in common with scientists' activities in that students "(1) learn in contexts constituted in part by ill-defined problems; (2) experience uncertainties and ambiguities and the social nature of scientific work and knowledge; (3) learning is predicated on, and driven by, their current knowledge state; (4) experience themselves as parts of communities of inquiry in which knowledge, practices, resources and discourse are shared; (5) in these communities, members can draw on the expertise of more knowledgeable others whether they are peers, advisors or teachers."

Inquiry-based learning, problem-based learning and authentic learning are primarily aimed at improving cognitive and procedural outcomes for students, though they also aspire to have affective benefits. Through their common the desire to encourage students to engage in activities where they behave like scientists, all emphasise open-ended investigative work, including the sort of work that occurs in practical research projects.

Perspectives from people associated with practical research projects

Part of the study reported in this chapter involved interviews with people associated with practical research projects, either through direct involvement or through their particular roles (e.g. organisers of a practical research project scheme). The interviews provided additional information about the purposes of practical research projects. In common with what was in the literature, the learning of science concepts and skills, and attitudes to science and science careers were seen as important. In relation to science concepts and skills, some concern was expressed about the potential for practical research projects to have an overly narrow focus, thus limiting the opportunities to develop a range of knowledge and skills. There was more consensus about impact on attitudes to science, with practical research projects seen as an important means of engaging young people with science and encouraging them to pursue careers in science. Other potential benefits were also identified in relation to students' personal development. These included increased self-esteem, encouraging students to be independent and autonomous learners, and practical matters such as organisational and time management skills.

The systematic review of research into the impacts of practical research projects in science

It is clear that practical research projects are perceived as having a number of benefits for students. The next section of this chapter considers the evidence that has emerged from research studies. To assess the impact of practical research projects, a systematic review was undertaken (Bennett, Dunlop, Knox, Reiss and Torrance Jenkins, 2016), addressing the following questions:

- What are the chief characteristics of practical research projects?
- What is the impact of participation in practical research projects on secondary school students' cognitive and affective responses to science?
- What are teachers' and students' perceptions of the value of practical research projects?

Review methods

The methods employed in the review draw on those developed by the Evidence, Policy and Practice (EPPI) Centre in its work on research syntheses in education (see, for example, Gough, Oliver and Thomas, 2012). In essence, these involve identifying a range of search terms and using these to search electronic databases for potentially relevant publications. These publications are then screened against arrange of inclusion and exclusion criteria to identify relevant publications. Key information is then extracted from the publications to enable judgements to be reached about the nature and quality of the evidence base.

A substantial challenge with the review was the identification of the relevant literature due to the wide variety of events, approaches and terms that may encompass practical research project activity. In order to ensure the search was as comprehensive as possible, the search terms used included authentic science, problem-based science, inquiry-based science, practical work, investigative work, independent practical work, extended practical work, extended project, science competition and science fair. The searches also included looking for the main individual branches of science, i.e. biology, chemistry, and physics.

Just over 1,400 publications emerged from the searches. These were narrowed down to thirty-nine publications reporting studies where the publication focused on:

- students aged 11-19 undertaking a practical research project in a science subject
- the project was undertaken over an extended period of time;
- students were involved in having a major input into the question(s) addressed by the project they were undertaking, together with having a leading role in the design of the project;
- the project involved production of a report or similar output that was assessed.

Additionally, the review was limited to publications from 2000 onwards as a most of the literature dated from that time. Practical research projects based solely on the manipulation and analysis of previously-obtained data (e.g. data downloaded from websites, or data from satellites) were excluded as they did not include a practical component.

The key information extracted from the studies included a brief description of the nature of the student practical research project itself, including its aims, chief characteristics (compulsory or optional, duration, organisations details, degree of student choice over questions, undertaken by individuals or teams, input from teacher or adult such as a university researcher, any associated external funding), and assessment details. For the research being reported in the studies, information was noted about the study aims, design, data collection methods and instruments, data analysis methods, and a summary of the findings and conclusions.

Further details of the review methods, including references for the 39 studies included in the review, may be found in Bennett, Dunlop, Knox, Reiss and Torrance Jenkins (2016).

Review findings

Box 2 summarises the characteristics of the practical research projects in the 39 studies.

Box 2: Characteristics of practical research projects

The majority of studies (70%) reported on practical research projects undertaken in the USA and the UK. (This figure is likely to under-represent work in other countries as the review was based on studies published in English.) Other countries where practical research projects were undertaken included Australia, Ireland, Israel, The Netherlands, New Zealand, Singapore, Spain and Turkey.

Practical research projects are most commonly undertaken by students aged 16+ (56%).

60% of practical research projects were described as being 'science' projects. Where the science discipline was reported, practical research projects are most commonly undertaken in biology, followed by chemistry and physics.

35% of practical research projects were undertaken in normal school hours, 25% outside school hours, and 40% using time within and outside normal school hours.

17 studies reported practical research projects being linked to other events. Of these, ten were linked to science fairs or competitions, five to summer camps, and two to external examinations.

20 studies reported details of funding. Of these, 15 project schemes were externally-funded and five were unfunded.

20 studies reported details of the involvement of other adults in practical research projects. Of these, all involved University staff and students and ten involved employers, with some using both.

25 studies reported details of products generated as part of practical research projects, and some projects required more than one product. Of these, written reports (76%) and oral presentations (68%) predominated, other products including an artefact and student reflective diaries.

A total of 89 outcome measures were used to assess the impact of practical research projects. The most common technique used to gather data from students were self-report questionnaires, interviews and focus groups. Data from students on conceptual understanding and the development of investigative skills was usually gathered via written tests. Affective responses were assessed via attitude, motivation inventories and self-efficacy inventories. Teacher data and data from other adults involved were gathered via interviews and questionnaires. Other outcome measures included assessment of student outputs and external test results.

The most striking aspect of the review was the diversity in the work. This diversity was apparent in both the nature of the practical research projects and the methods used to evaluate the impacts of the projects.

Table 1 summarises four of the studies reported to illustrate the diversity in practical research projects.

Experimental designs of some form were used in just over a quarter of the studies employed to enable comparisons to be made between groups of students who did, or did not, undertake practical research projects, though none of these took the form of randomised controlled trials (RCTs). Occasionally, use was made of other datasets, such as external examination results, to make comparisons between students undertaking practical research projects and the wider student population. Three-quarters of the studies gathered data only from participants. Most studies drew on more than one source of data. However, there were no examples of instruments used in one study being used in another study.

Methods used to evaluate the cognitive impacts of the practical research projects on students included assessments of conceptual understanding, views of the nature of science and levels of scientific literacy. Affective impacts on students were assessed through measures of attitudes to science, creativity, motivation and self-efficacy. Other assessments included practical skills, use of technology and more general skills such as collaborative working. Some studies looked specifically at impacts on groups traditionally under-represented in science, exploring factors such as gender, ethnicity and socioeconomic status. Self-report data, most usually from interviews, was also gathered from students, teachers and other adults involved in the practical research projects.

Other data sources were occasionally used, including information in students' reports on their practical research project, artefacts produced for the projects, external datasets including test and examination results, and observation of project activity.

The impact of practical research projects

The diversity in the practical research projects and in the methods used to evaluate their impacts poses a challenge in synthesising the evidence.

Almost all publications report benefits to participation in practical research projects. Such a finding is unsurprising. Those interested in the area are likely to believe that such projects will be beneficial. Additionally, though the authors of a publication rarely state specifically their relationship to the work being reported, the nature of interventions such as practical research projects means that research into impact will often be conducted by those associated with the development and/or the running of the practical research project. This was the case in most of the studies, with externally-commissioned evaluations being rare. (Two examples of external evaluations are Grant, 2007 and Jenkins and Jeavans, 2015).

Table 1: Examples of practical research projects (based on Bennett *et al.*, 2016)

Publication	**Burgin et al., 2007**	**Charney et al., 2007**	**Chin and Chia, 2004**	**Hubber et al., 2010**
Source of publication	Research in Science Education	International Journal of Science Education	Journal of Biological Education	Teaching Science
Name of scheme	Student Science Training Programme (SSTP)	Waksman Student Scholars programme (WSSP)	No specific name	BHP Billiton Science Awards
Country	USA (Florida)	USA (New Jersey)	Singapore	Australia
Student age range	16-17	15-17	14-15	11-15
Science discipline	Chemistry	Biology (genetics)	Biology (food and nutrition)	Science
External groups involved	University: mentor scientists	University (mentor scientist)	None	'External professionals' mentioned
Nature of student participation	Individuals	Teams	Teams	Individual
Duration and when undertaken	Summer residential school (7 weeks)	Summer school (4 weeks) plus 25 hours in-school follow-up	18 weeks during school time	During and outside school time over a period of several weeks
Linked events	None	None	None	Can be presented at science fairs
Funding	Charitable grant	National Institutes of Health, the National	None	BHP Billiton (industrial sponsor)

		Science Foundation, industrial funding and funding from partner university		
Number of participating students	18 (including seven females and 7 from ethnic minority groups)	30 (including 17 females, 18 from ethnic minority groups)	39	65
Student product	Research report and presentation	Poster presentation	Team report and presentation	Not explicitly stated
Impact outcome measures	Student interviews Mentor (scientist) interviews Concept maps	Student diaries Assessment of conceptual knowledge Assessment of views of nature of science	Student questionnaire Student interviews Observation, audio and videotapes of group work	Student questionnaire Teacher interviews Student interviews State organiser interviews
Links to wider initiatives	Authentic science	Authentic science	Problem-based learning (PBL)	Authentic science
Practical research project focus	Students undertake projects on "genuine unanswered questions" in chemistry	Students engage in a variety of open-ended projects linked to genetics research	Students developed projects based on newspaper reports of food and nutrition issues	Students undertake a variety of open-ended science projects
Reported outcomes	Student reported improved scientific knowledge; this was supported by data from concept maps Four students reported increased	Improved student knowledge, broader awareness of nature of science, promotion of collaborative learning environment.	Most students viewed practical research project work positively and enjoyed the freedom to work in new ways Students less confident	Most students reported increased interest in science Teachers reported increased post-compulsory uptake of sciences

	interest in pursuing a career in research science		about giving presentations PBL approaches are time-consuming	Teachers reported positive response from students normally less successful in science

The frequent close association of the authors of publications reporting on the impact of practical research projects points to a potential problem with the research: those undertaking the work may be inclined to want to gather data that point to positive impacts. In practice, and despite the limited use of experimental designs to enable comparisons to be made, there were no examples of inappropriate designs being used, nor any of designs being used that would limit that nature of the data collected to the point where they were likely to reflect a biased assessment of impact.

Benefits reported for practical research projects were reported in a number of areas. Much of the work concentrated on impacts on students, and, in particular, their responses to participation in practical research projects, improvements to their learning, and their more general attitudes to science as a result of participation in practical research projects, including attitudes to pursuing a career in science. The impacts on teachers and other participants (university scientists and employers) were also reported in a number of the studies. A further strand of the work focuses on aspects of the widening participation agenda.

Table 2 illustrates the key findings from selected studies.

Table 2: Main findings from selected studies (see also examples in Table 1)

Study	**Country**	**Student age**	**Focus of practical research project**	**Key findings**
Adams *et al*. (2009)	USA	12-17	Air pollution and respiratory health	• Improved understanding • Improved awareness of the importance of record keeping and the need for systematic data collection • Two-thirds of students reporting increased in interest in becoming a scientist.
The British Science Association (2014)	UK	16-18	CREST projects	• Valued by students and teachers • Promote teamwork and creativity • Improved student attitudes to STEM education and careers • Improves student practical and technical skills • Attractive to both male and female students and higher-than-average take-up by students from lower socio-economic groups
Haigh (2007)	New Zealand	15-16	Biology projects	• Improved creativity • Required careful management by teachers to be effective

Hubber *et al*. (2010)	Australia	11-15	BHP Billiton Science Awards	• 75% of students reported increased interest in science and 50% of student reported improved marks in science • Students valued authentic reflection of scientific activity and links with science professionals • Teachers reported improved post-compulsory uptake of science subjects
Jenkins and Jeavans (2015)	UK	7-18	Royal Society Partnership Grants	• Increased student confidence • Increased student knowledge of STEM subjects, and positive perceptions of scientists • High levels of satisfaction amongst teachers and participating partners (universities, employers) • Teachers valued student satisfaction with projects and professional development through participation
Krajcik and Blumenfeld (2006)	USA	11-13	Project-based science	• Statistically significant student learning gains on external tests of achievement • Student attitudes to science remaining positive over lower high school years, rather than declining
Nuffield Foundation (2013)	UK	16-18	Nuffield Research Placements	• Student acquire better understanding of what it means to be a scientist, and knowledge of the range of jobs in which scientists engage • Particular benefits for students from disadvantaged backgrounds • Impacts on students' learning and skills less obvious
Rivera-Maulucci *et al*. (2014)	USA	11-12	Authentic Science Inquiry Investigation	• Improved student achievement in science • Improved student 'agency' (i.e. what they know about science and how scientists work) • Improved student participation in after-school science clubs in year

				following undertaking of practical research projects
Schneider *et al*. (2002)	USA	15-17	Project-based science	• Significantly higher performance on more than half the items in national test of knowledge, skills and application in science

An additional evaluation of the CREST Awards in the UK (Stock Jones, Annable, Billingham and Macdonald, 2016), published after the systematic review was completed, looked at the impact of participation on student attainment in external examinations at 16+ and likelihood of pursuing further study of STEM (Science, Technology, Engineering, Mathematics) subjects. The study reported participating students achieving statistically significant improvement in results for external examinations in science, with the gains being most appreciable for disadvantaged students of lower socio-economic status. There were also statistically significant increases in numbers continuing with their study of STEM subjects, again with the most appreciable differences being for disadvantaged students.

Relatively few negative impacts were noted. Those reported included the time demands of the work, adverse effects on teaching time for normal course materials where practical research projects were undertaken in normal school hours, difficulty in finding university or employer partners, and low teacher confidence in running practical research projects. In contrast to most studies, Kennedy (2014) reported teachers feeling that participation in practical research projects *discouraged* students in Ireland from pursuing further study of science. Similarly, Sikes and Schwartz-Bloom (2009) reported a slight *decrease* in interest from students from traditionally-under-represented groups in the USA after participation in practical research projects.

A more detailed consideration of the review findings may be found in may be found in Bennett, Dunlop, Knox, Reiss and Torrance Jenkins (2016, 2018).

The views of students and teachers participating in practical research projects

This section of the chapter considers the views of students and teachers on the impact of participation in practical research projects. It draws on eight group interviews with a total of 39 students, and three interviews with teachers.

Students' views

Students' views of practical research projects were largely positive, with students displaying a high degree of commitment to their project. Many students reported that participation in a practical research project was an opportunity to reinforce and expand their scientific knowledge and to develop practical expertise in a scientific field.

A common view amongst students was that the practical research project provided them with an authentic experience through which they learnt how science is done, and what it is like to be a scientist. They enjoyed working on live and topical problems with experts in the field, manipulating specialist equipment and interpreting raw data.

Students also identified that, through their practical research project, they had been involved in a communal experience that was more in line with how science really works, with scientists often working in research groups rather than in the individualized way they are used to working in school.

Students felt that their academic performance was improved, and they also had more confidence in their scientific knowledge, practical skills, skills in data collection and analysis, and communication skills as a result in participation in practical research projects.

As they had already made the choice to study one or more science subjects, students had positive attitudes towards science before undertaking their practical research projects. Students described their project work as stimulating and exciting, as well as fun, enjoyable and interesting, and particularly valued the associations with other people who enjoyed science.

All students described their practical research project work as influential in their future career and study choices. For many, undertaking a practical research project had confirmed their desire to study science and, through broadening their knowledge of the career opportunities associated with studying science, had increased their desire to pursue a career in STEM. Additionally, students felt they had a better idea of what employers are looking for, and that they were better able to communicate professionally with employers.

When students were asked how working on a practical research project compared with standard practical work, most commented on the substantial differences. The freedom, ownership and excitement of their practical research project, where outcomes were unknown, and which often focused on contemporary science, was contrasted with conventional practical work, which they described as giving a false sense of what science is about and designed to confirm ideas that had already been discovered.

Students identified some challenges and problems associated with participating in a practical research project. Most frequently mentioned was the challenge of balancing the demands of their project work with other academic studies and managing the dynamics of working in a team. They also commented on the frustrations and failures that they had experienced. These included what they described as the less glamorous activities such as cleaning and setting up equipment, ensuring health and safety issues were adequately addressed, and spending long, repetitive days in the laboratory, sometimes for little or no tangible result.

Teachers' views

Teachers were positive about practical research projects, though some reservations were also expressed. They identified a number of benefits for students. These included the opportunity to experience 'real' science, to be part of a scientific community and to develop a range of skills that were not normally associated with the science curriculum, such as teamwork and communication skills. They also felt practical research projects were a good way to get students involved in science, develop their confidence, and help them feel more positive about science and careers involving STEM subjects.

The principal drawback for students, in the view of teachers, was difficulties with managing time, with some students neglecting their normal work to focus on their projects. Additionally, it could be disheartening for students if a considerable amount of effort did not yield the hoped-for results.

For teachers, the main benefit of becoming involved in running practical research projects was seeing their students really engaged and inspired by their subject. This was both motivating and reinvigorating. Teachers also reported that participation in practical research projects provided them with good professional development, personal and professional satisfaction, and improved relationships with their students. The challenges and drawbacks for teachers were associated with resource constraints, their confidence in being able to support students with their projects, identifying potential partners outside school for practical research project work, workload and time constraints. Teachers also cited the importance of a supportive culture in schools as being crucial to the successful implementation of practical research projects, as was the need for a good organisational structure to support undertaking the projects.

Conclusions

This chapter set out to look at the evidence on the impact of participation in practical research projects on students' learning in science and engagement with science. What does the research evidence indicate?

There is little doubt of the support for practical research project work. It is often associated with national policy initiatives and is seen as important and valuable by a range of people involved in science education, including teachers, educational researchers, scientific researchers, employers, government organisations, learned societies and charitable foundations, as well as students themselves.

Practical research projects are offered to students in a number of countries, across the high school age range and in all the major science disciplines. The nature of practical research project provision is diverse, though always linked to the belief that it will result in positive outcomes for students in terms of their learning and/or attitudes to science, and to positive outcomes for other groups, including teachers, scientific researchers and employers. Increasingly, practical research projects are seen as a means of addressing the widening participation agenda in science and engaging traditionally under-represented groups of students. Opportunities to participate in practical research project work are offered to students within schools in lesson time, dedicated blocks of timetabled hours and school science clubs. Outside school hours, students can participate in practical research project work as summer schools and camps. Students may also get the opportunity to present their work at science fairs and competitions.

A wide range of features and attributes of practical research projects have been explored, of which the most common are cognitive and affective impacts on students, and teachers' and others' views of the impacts of practical research projects.

The evidence on impact is extensive, revealing considerable diversity in the projects undertaken by students, the nature of the impacts explored and the measures used to assess impact. In considering the strength of the evidence as a whole, account needs to be taken of issues to do with the nature of the data gathered. The majority of studies do not involve experimental designs, thus do not enable comparisons to be made with students who have not undertaken practical research projects. Often, impact studies are undertaken by people who have been involved in some capacity with the design and implementation of the practical research project. Equally, it is inevitable that those in favour of practical research project work will predominate in any consideration of the literature, particularly where participation in practical research projects is optional, which is very often the case. Additionally, a considerable quantity of the data takes the form of self-report data from questionnaires and, in particular, interviews. Each of these factors has the potential to create an overly-positive picture of impact.

Despite the caveats, some consistent messages do emerge. Practical research projects can be very positive experiences for students, leading to improved learning of science concepts and an appreciation of science that extends beyond what would be encountered in the standard curriculum. The projects can also result in improvements in affective factors such as attitudes and motivation, and improvements in a wide range of practical and research skills. Additional benefits reported include increases in a sense of scientific identity, independence and autonomy, self-esteem, self-regulation, tenacity and time management skills. Finally, there is evidence to suggest that more students are likely to consider careers in science as a result of their participation in practical research projects, and that there are particular benefits for students from traditionally under-represented backgrounds. Set against these positive outcomes are issues to do with time for both students and teachers and providing support for teachers such that they feel confident in running practical research projects and that the work takes place in the context of wider support within their schools. to run practical research projects with confidence.

Currently only a very small number of students have the opportunity to undertake practical research projects. This work reported here suggests that there is sufficient evidence to explore ways in which many more high school students can be provided with opportunities to participate in practical research project work. Such a move would require the support of those responsible for the formulation of educational policy and the curriculum. Key aspects to emphasise would include the positive impact practical research projects can have in relation performance in science, attitudes to science and science careers. In a climate where there is concern about the number of under-represented groups in science, the potential contribution to the widening participation in science seems particularly worth noting. Additionally, practical research projects can make a valuable contribution to building links between schools and the wider community, including employers.

Increasing practical research project provision places particular demands on students and on teachers, and also on universities and employers, where they are involved. Many of these demands are not associated with more conventional school science provision. This suggests that some form of training and support should be provided for each of these groups prior to embarking on practical research project work.

Successful practical research project programmes require organisational structures and networks of support for teachers, together with financial support, and these aspects need to be thought through carefully if schools are to be given more encouragement to offer practical research project work. Organisational structures could include guaranteed time in schools, or a school science club, or an external structure, such as a science competition or fair, or a network that helps teachers identify interested staff in universities and employers. External funding to support practical research projects comes from a range of sources, including government agencies, charitable bodies, industrial sponsors and other groups that fund research. Building more links with industrial partners may provide a way to augment the current funding provided by charitable groups. There is a case for establishing co-ordinating bodies to support practical research projects. One example of such a group is the Institute for Research In Schools (IRIS), launched in the UK in 2016, which identifies funding opportunities, training opportunities, and interested external partners.

Many countries face challenges in recruiting people to science and STEM careers. Practical research projects have the potential to contribute to solutions to this problem. The evidence suggests that they can provide a way of engaging more students with science through trying to answer problems in real-life contexts and, in turn, this can encourage more students to pursue their study of science and consider careers in science.

References

Adams, E., Ward, T.J., Vanek, D., Marra, N., Hester, C., Knuth, R., Spangler, T., Jones, D., Henthorn, M., Hammill, B., Smith, P., Salisbury, R., Reckin, G., & Boulafentis, J. (2009) The Big Sky inside. *Science Teacher, 76*(4), 40-45.

British Science Association. (2014) *CREST Evaluation Summary*. Unpublished internal document.

Burgin, S.R., Sadler, T.D., & Koroly, M.J. (2012) High school student participation in scientific research apprenticeships: Variation in and relationships among student experiences and outcomes. *Research in Science Education, 42*(3), 439-467.

Charney, J., Hmelo-Silver, C.E., Sofer, W., Neigeborn, L., Coletta, S., & Nemeroff, M. (2007) Cognitive apprenticeship in science through immersion in laboratory practices. *International Journal of Science Education, 29*(2), 195-213.

Chin, C., & Chia, L-G. (2004) Implementing project work in biology through problem-based learning. *Journal of Biological Education, 38*(2), 69-75.

Grant, L. (2007) *CREST Award Evaluation: Impact Study*. Liverpool: University of Liverpool. Retrieved October 2015 from http://www.britishscienceassociation.org/crest-evaluation.

Haigh, M. (2007) Can investigative practical work in high school biology foster creativity? *Research in Science Education*, *37*(2), 123-140.

Hubber, P., Darby, L., & Tytler, R. (2010) Student outcomes from engaging in open science investigations. *Teaching Science, 56*(4), 8-12.

Jenkins, S., & Jeavans, E. (2015) *Evaluation of the Royal Society Partnership Grants Scheme: Full Report*. Unpublished internal document, The Royal Society/Jenesys Associates.

Kennedy, D. (2014) The role of investigations in promoting inquiry-based science education in Ireland. *Science Education International, 24*(3), 282-305.

Krajcik, J.S., & Blumenfeld, P. (2006) Project-based learning. In R.K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*. Cambridge: Cambridge University Press.

Rivera Maulucci, M.S., Brown, B.A., Grey, S.T., & Sullivan, S. (2014) Urban middle school students' reflections on authentic science inquiry. *Journal of Research in Science Teaching, 51*(9), 1119-1149.

Schneider, R.M., Blenis, J., Marx, R.W., & Soloway, E. (2002) Performance of students in project-based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching, 39*(5), 410-422.

Sikes, S.S., & Schwartz-Bloom, R.D. (2009) Direction Discovery: A science enrichment program for high school students. *Biochemistry and Molecular Biology Education, 37*(2), 77-83.

Bennett, J., Dunlop, L., Knox, K.J., Reiss, M.J. & Torrance Jenkins, R. (2018) Practical Independent Research Projects in science: a synthesis and evaluation of the evidence of impact on high school students. International Journal of Science Education, 40 (14), 1755-1773.

Bennett, J., Dunlop, L., Knox, K.J., Reiss, M.J. and Torrance Jenkins, R. (2016) A Rapid Evidence Review of Practical Independent Research Projects in Science. Wellcome Trust, London. https://wellcome.ac.uk/sites/default/files/review-of-practical-independent-research-projects-in-science-wellcome-apr16.pdf

Gough, D., Oliver, S., & Thomas, J. (2012) *An Introduction to Systematic Reviews*. London: Sage.

Hmelo-Silver, C. (2004) Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3), 235-266.

Millar, R. (2004) *The Role of Practical Work in the Teaching and Learning of Science*. Paper prepared for the Committee: High School Science Laboratories: Role and Vision. Washington, DC: National Academy of Sciences.

Minner, D., Levy, A., & Century, J. (2010) Inquiry-Based Science Instruction—What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002. *Journal of Research in Science Teaching,* 47 (4), 474-496.

Roth, W-M. (1995) *Authentic School Science Knowing and Learning in Open-Inquiry Science Laboratories.* The Netherlands: Kluwer.

Stock Jones, R., Annable, T., Billingham, Z. and Macdonald, C. (2016), Quantifying CREST. London: British science Association.